BELLCOMM, INC.
1100 Seventeenth Street, N.W. Washington, D.C. 20036

SUBJECT: Experiment Payload for Manned Venus Encounter Mission -- Venus Tracking and Data Orbiter - Case 710

DATE: June 13, 1968

FROM: M. M. Cutler

ABSTRACT

In Bellcomm TR-68-710-2, subject "Experiment Payloads for Manned Encounter Missions to Mars and Venus," a 1977 triple planet flyby mission was selected to illustrate a possible experiment program to explore Venus and Mars during their respective encounter phases. One of the probes considered for deployment at Venus is an orbiter serving as an atmospheric balloon tracking station and Earth data relay link. The basis for the conceptual design of this orbiter is described. Preliminary analysis indicates that a probe of approximately 5750 lbs, as ejected from the flyby spacecraft, can be placed in a circular orbit at an altitude of 4000 km around Venus during the first encounter of the mission utilizing a two-stage liquid propulsion system. Final weight in orbit is approximately 510 lbs. A phased array antenna enables the satellite to track a complement of super-pressure balloons at various locations in the Venus atmosphere for a period of 30 days. An omni-directional antenna permits the orbiter to relay the data to Earth at a rate commensurate with the available time. Power is provided directly by a solar array.

(NASA-CR-95519) EXPERIMENT PAYLOAD FOR MANNED VENUS ENCOUNTER MISSION - VENUS TRACKING AND DATA ORBITER (Bellcomm, Inc.) 18 p

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MEMORANDUM FOR FILE

INTRODUCTION

Mission opportunities have been identified for free return manned flyby (or encounter) of Venus and Mars. Reference 1 discusses a 1977 Earth-Venus-Mars-Venus-Earth mission to illustrate a possible experiment program to explore Venus and Mars during the respective encounter phases. Two of the four types of probes considered for deployment at Venus are a meteorological balloon probe distributing super-pressure balloons in the Venus atmosphere to assess atmospheric characteristics and a companion orbiter serving as a balloon tracking station and Earth data relay link.

This memorandum reports the results of the study that was conducted to arrive at the conceptual design of the relay-orbiter. A companion memorandum is devoted to the meteorological balloon probe.[2]

MISSION CONCEPT

In the triple planet mission, meteorological balloons are deployed in the Venusian atmosphere to measure some of the thermodynamic parameters and gross circulation patterns.

The structure of the Venus atmosphere is not well-defined. Models of the atmosphere and its circulation have been largely inferred from a combination of theory and Earth-based optical, IR, and radio wave observations. In view of the harsh environment (high surfaces temperatures, high upper atmosphere winds) anticipated by some investigators, the life-time of the balloons is uncertain. Consequently, the approach taken was to use an orbiter to track the balloons, obtain their data, and relay the data to Earth. This approach results in less weight and complexity of communications equipment than that required if each balloon communicated directly with Earth.

The intimate relationship between balloon location and orbiter ground track, as well as the need to have the orbiter working at the time the balloons are deployed, requires coordination of the injection of the two probes.

The various elements of the companion systems (balloon and orbiter) are intended for a 30-day life. This selection was largely tempered by the estimated survival time of the balloons. However, it may be feasible to shut down the orbiter and reactivate it at a later date. This would be appropriate if another set of balloon probes were deployed at the time of the flyby vehicle's second Venus encounter. By carrying a second orbiter with the set of balloon probes, the crew can conduct the second experiment utilizing one or both orbiters. Further, a year will have elapsed between first and second encounters and the second experiment can be modified to take advantage of information developed from the first meteorological experiment.

MISSION PROFILE

The trajectory parameters of the representative 1977 triple planet mission are:(3)

Encounter	V_∞, km/sec	Periapsis Passage: Altitude, km	Periapsis Passage: Velocity, km/sec	Inclination to Planetary Orbital Plane
First Venus	6.7	680	11.8	80.4°
Mars	4.4	3960	5.6	60.3°
Second Venus	7.1	700	12.0	80.5°

The encounter geometry at Venus is shown in Figure 1.(1)

The desired parking orbit of the relay orbiter is a trade-off between tracking system power for a desired spatial resolution of balloon position, planetary surface area coverage, and deboost ΔV. As circular orbital altitude increases, the required deboost ΔV decreases to a minimum, surface coverage increases and so does the required power for the tracking system. From preliminary considerations of antenna gain, antenna aperture, and power requirements, a circular orbit of 4000 km altitude was selected.(4)

Initially, circular orbits as low as 500 km were considered, largely because of the opportunity that such an orbit offers for other experiments, such as phototography. Resulting antenna configurations were high aspect-ratio, "wing-like" designs with wide search widths (perpendicular to ground track) and shallow depths (parallel to ground track).(4) Ground speed was high (423 km/min) and design of the antenna was difficult, requiring such devices as multiple folding panels with cantilevering.

When other considerations, principally the total mass to be deboosted, showed that it was inadvisable to combine the tracking-relay function of the orbiter with requirements such as photography, higher altitude orbits (elliptical as well as circular) were considered. Remaining at a high altitude has several advantages: a greater surface area may be "viewed" at any instant, time lines are longer due to the increased orbital period, and the energy to deboost from the hyperbolic flyby is less. It also avoids the planet contamination problem, eliminating the need for probe sterilization.

Elliptical orbits largely satisfy the reduced energy-to-deboost criterion (5) but offer little else. The useful operating altitude is generally constrained (by antenna and power considerations) to the region of periapsis, where the orbiter will have a higher ground speed than a circular trajectory at periapsis altitude, and the surface coverage will not be any better than that of a circular orbiter. Further, the lowest altitude coverage should occur over the largest fraction of the orbit. Consequently, although the deboost energy requirement is higher, a circular orbit was selected in preference to an elliptical orbit since it offers a wider latitude insofar as time lines and balloon deployment are concerned.

Since periapsis passage altitude of the parent spacecraft is about 700 km on both encounters, the orbiter probe will be separated prior to Venus encounter and injected into a trajectory with a periapsis passage height of 4000 km. Entry path angle considerations dictate placement of the balloons in the region of the sub-Earth and anti-Earth points(2) (see Figures 1 and 2). Consequently, the altitude adjustment will be combined with a plane change maneuver so that the orbiter passes over the balloon target area.*

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*Further study is necessary to examine the alternative sequence of injecting the balloons after the relay is functioning in orbit.

Parameters of the tracking and data relay satellite orbit are:

altitude = 4,000 km
orbit radius = 10,050 km
orbit velocity = 340.8 km/min
orbit period = 185 min
angular velocity = 1.95°/min
ground speed = 206 km/min

Some additional rotation of the orbit plane may be desirable after the orbit has been established.

Figure 3 illustrates the relay orbiter tracking profile. The antenna angle of 55° defines the width of the search beam. The combination of antenna angle and orbital motion serves to sweep a ground track with a planet central angle of 45°. As a result approximately 42% of the potentially "visible" surface (area included within angle subtended by the planet limbs) may be seen on each orbital revolution.

COMMUNICATION LINK

A. System Requirements

The function of the orbiter is to track the balloons on each successive orbit, acquire meteorological data from the balloons, and relay this total information to Earth and possibly the flyby spacecraft during the time it is within communication distance. Consequently, the orbiter requires a balloon tracking-data-acquisition subsystem and an Earth-Venus command-data link.

1. Tracking-Data-Acquisition Subsystem

The meteorological experiment will deploy 12 balloons in two groups of six (Figure 2). In the course of one orbital period of approximately 3 hours, each balloon will record approximately 800 bits of data. For each of the twelve balloons to be contacted on each orbit, the requirement upon the tracking-data-acquisition subsystem is to search the surface with the widest feasible beam width, locate each balloon and acquire the meteorological data that the balloon has recorded since the last contact.

The constraints on the tracking subsystem are:

a. Tracking system of the orbiter must be compatible with the ground speed so as to permit marking, ranging, and interrogating each balloon on each passage.

b. The subsystem must be capable of coping with a maximum of six balloons in the ground pattern at any instant.

c. Antenna design should be compatible with the orbiter configuration.

2. Earth-Venus-Command-Data Link Subsystem

The Earth-Venus command-data link must deliver approximately 10,000 bits of data (12 balloons, 800 bits per balloon) to Earth on each orbit. The mission-peculiar constraints are that communication distances between Earth and Venus for the two encounters vary from 0.6 A.U. to 1 A.U.[3] and that orbiter will be partially occulted by Venus (as seen from the Earth) so that maximum communication time is approximately 130 minutes per orbit. This time availability is a mild constraint at first Venus encounter, but may be a severe constraint at second encounter where there is a capability for using two orbiters.

The balloon tracking mode is best served by a planet-centered attitude control system whereas the Earth-Venus communication mode is best served by an Earth-pointing attitude control system. (An objective of the configuration analysis was to minimize the need for articulating or deployable structures.)

B. <u>Balloon Tracking and Data Acquisition Subsystem</u>

The balloon tracking communication system is made up of a square array antenna, approximately 55 inches on a side, with 10 rows of 10 elements each. The antenna aperture (Figure 3) is 55° and the search beam is 55° crosstrack and 5° downtrack. This system with its auxiliary electronics and logic weighs approximately 135 lbs and requires 100 watts of regulated power.[4]

In principle the tracking system operates in two modes, search and acquisition. During search the antenna is phased in one plane and generates a beam 55° wide that sweeps the surface due to the orbiter's motion. When a balloon is acquired, the antenna is fully phased and the search beam focuses to a 5° conical beam that tracks the balloon while the meteorological data is acquired. After data acquisition the system returns to the search mode. A more detailed explanation of the operation is presented in Appendix A.

C. <u>Earth-Venus Command-Data Link</u>

The principal considerations in selection of this subsystem were communication distance, information quantity, and available transmission time. The assumption was made that an Earth-based receiver will always be available. The orbiter acquires about 10,000 bits per orbit. To deliver this at a high data rate, say 1 kbs, requires a large and highly directional antenna on the orbiter and 20-50 watts of radiated power. Further, since one set of balloons is deployed at the sub-Earth point on first Venus encounter simultaneous operation of the balloon tracking system and Earth data link would be required for short periods. Simultaneous operation of the balloon tracking system and a directional Earth pointing antenna would require articulation of the antenna as well as a control system to acquire and hold the Earth station. Reorientation of the satellite would be precluded.

On the other hand, a data rate of 5 bps would permit an omni-directional antenna for approximately the same power requirement. This eases the antenna pointing problem but increases the communication time from approximately 10-20 seconds to 33 minutes. Since the time may be doubled on the second Venus encounter, if both orbiters are working, the time requirement could be significant.

Taking the above points into consideration, the Earth-Venus command-data subsystem was configured as an omni-directional antenna system supplied with 70 watts of regulated power. System weight is 15 pounds and data rate is 5 bps.[4]

POWER SYSTEMS

The principal consumers of power are the balloon tracking subsystems, the Earth command-data link, and the attitude control system. The estimated power requirements are:

Balloon tracking: 100 watts, avg.
Earth command-data link: 70 watts, avg.
Attitude Control Systems: 50 watts, avg.
Housekeeping: 50 watts, avg.

The relay orbiter's dimensions (Figure 4) permit a projected sunlit area of more than 30 sq. ft. of solar array. At Venus, the solar array will generate 10 watts of power per projected square foot of solar array. Consequently, more than 300 watts of electrical power are generated. The relay is not occulted with respect to the sun during the 30-day period following insertion into the Venus orbit on either encounter. Since the maximum demand is approximately 280 watts, the power system may be designed to run directly off the solar array. A secondary battery (6 ampere-hour, 24 volt,20 cell, Ni-Cd, 144 watt-hour) would also be installed in order to provide power for short term contingencies and for the period after spacecraft separation and up to Venus orbit insertion.

The balloon tracking system does not have to be operating continuously. Since the balloons will be initially deployed in groups of six, 156° apart, the tracking subsystem can be turned on when the relay orbiter is approximately 45° from initial balloon zenith and turned off approximately 45° after zenith passage. On this basis, the tracker would be operating on a 50% duty cycle. The effect on subsystem life of operating in this mode requires further study.

The ACS will be operating in a limit cycle mode and may be partially turned off for long periods (horizon scanning loop for stabilization of local vertical) if gravity gradient stabilization can be successfully applied. The Earth command-data link will be operating for approximately 2000 seconds per orbit (10,000 bits at 5 bps) or approximately a 33% duty cycle.

ATTITUDE CONTROL SYSTEM (ACS)

As noted earlier, the tracking mode requires a planet centered orientation. Since the mass distribution and moments of inertia have not been determined, the ACS selected for purposes of this study is based on similar subsystems already in operation, Nimbus and Lunar Orbiter, as well as more advanced studies already completed.[6] The ACS would use horizon sensors and a cold gas reaction control system to point the balloon tracking antenna down the local vertical. Limit cycle bandwidth would be less than 1°. System weight would be 90 lbs, and power consumption approximately 50 watts of regulated power. Gravity gradient stabilization is very attractive and developments in this area should be applied as feasibility is demonstrated.

ANCILLARY SUBSYSTEMS

A weight of 35 lbs has been reserved for ancillary equipment such as a recorder, a programmer, and associated electronics.

PROPULSION SUBSYSTEM

The propulsion subsystem has been defined on the assumption that the maneuvers to adjust periapsis passage altitude and initial orbit plane are performed at Venus encounter and some reserve is kept for orbital plane changes after orbit insertion.

Based on a final weight of 510 lbs in Venus orbit, the probe propulsion system would be a 2-stage hypergolic bi-propellant system with a vacuum specific impulse of 325 seconds. Stage I requires two burns, one at injection to change the periapsis passage altitude and initial orbit plane and a second at periapsis to initiate insertion into planetary orbit. Stage II completes the insertion.

The total velocity change requirement of 6.25 km/sec is comprised mainly of the de-boost velocity change (approximately 5 km/sec) plus a mid-course allowance (approximately 500 meters/sec) for adjustment of periapsis height and orbital plane inclination. The balance of the budgeted velocity change represents a design reserve and a capability for further maneuvering after orbit insertion. This total velocity change requirement was divided equally between the two stages. Probe weight is based on impulsive burning, a propellant fraction of 0.87, and a final weight in orbit of 510 lbs. The gross weight of Stage I is 4040 lbs and propellant weight is 3590 lbs. The gross weight of the Stage II propulsion system is 1200 lbs, and the propellant weight is 1065 lbs.

Each stage would have a single radiation cooled thrust chamber sized for about 1-g thrust loading. Four spherical tanks would contain the Stage I propellants and two tanks would be required for Stage II.

The relay orbiter weight summary is as follows:

Relay Orbiter		510 lbs
Power & Thermal Control Subsystem	150 lbs	
Communication Subsystem	150 lbs	
Attitude Control System	90 lbs	
Structure	85 lbs	
Equipment	35 lbs	
Stage II Propulsion System		1200 lbs
Propellants	1065 lbs	
Inert components	135 lbs	
Stage I		4040 lbs
Propellants	3590 lbs	
Inert components	450 lbs	
	TOTAL	5750 lbs

CONCLUSION

This study of a Venus relay orbiter has shown that a useful vehicle can be designed for a weight of approximately 510 lbs in orbit and 5750 lbs as launched from the flyby spacecraft. In the course of this study it became apparent that additional studies would be useful in further defining the concept:

1. Search subsystem -- Optimization of the relationships between antenna angle, orbit characteristics, power required, and design feasibility.

2. Mission profile -- Planet approach sequence to minimize velocity and direction changes.

3. Power system -- Power system sizing based on improvements in the state-of-the-art of secondary battery systems and solar arrays.

4. Stabilization and control -- Use of a gravity gradient system, not only to reduce the weight of the cold gas ACS, but also to improve pointing accuracies.

5. Thermal control -- Feasibility of passive thermal control at a distance of 0.7 A.U. from the sun and alternate thermal control systems.

6. Propulsion system -- Strategy for the ΔV distribution between the two propulsive stages. Examination of higher energy and lower specific volume systems.

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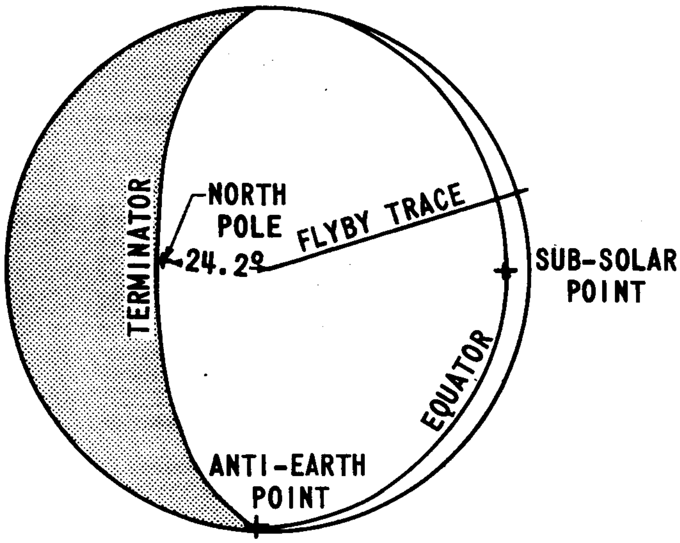
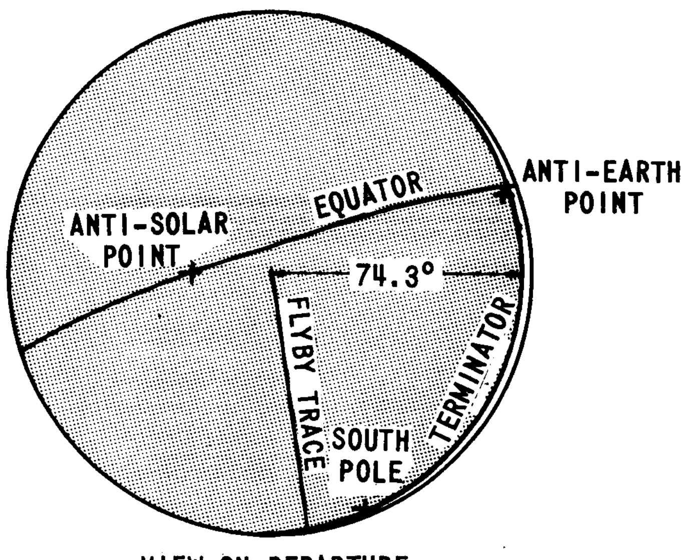


VIEW ON ARRIVAL



VIEW ON DEPARTURE

FIGURE I - FIRST VENUS ENCOUNTER - VIEW ON ARRIVAL AND DEPARTURE

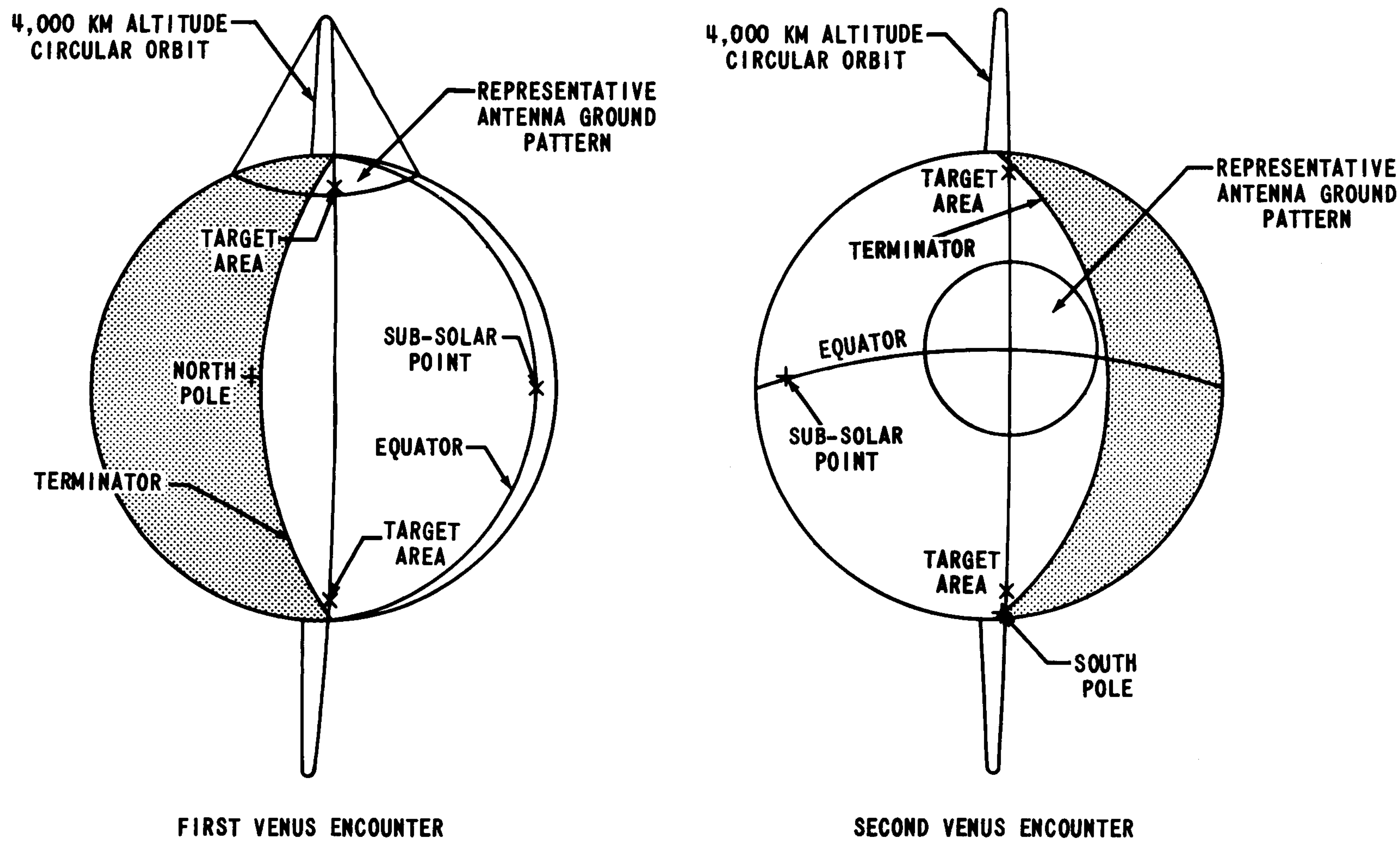


FIGURE 2 - METEOROLOGICAL BALLOON PROBE TARGET AREAS AND INITIAL ORBIT OF RELAY SATELLITE

ALTITUDE = 4,000 KM
ORBIT RADIUS = 10,050 KM
PERIOD = 3.08 HRS.
ORBITAL VELOCITY = 5.65 KM/SEC

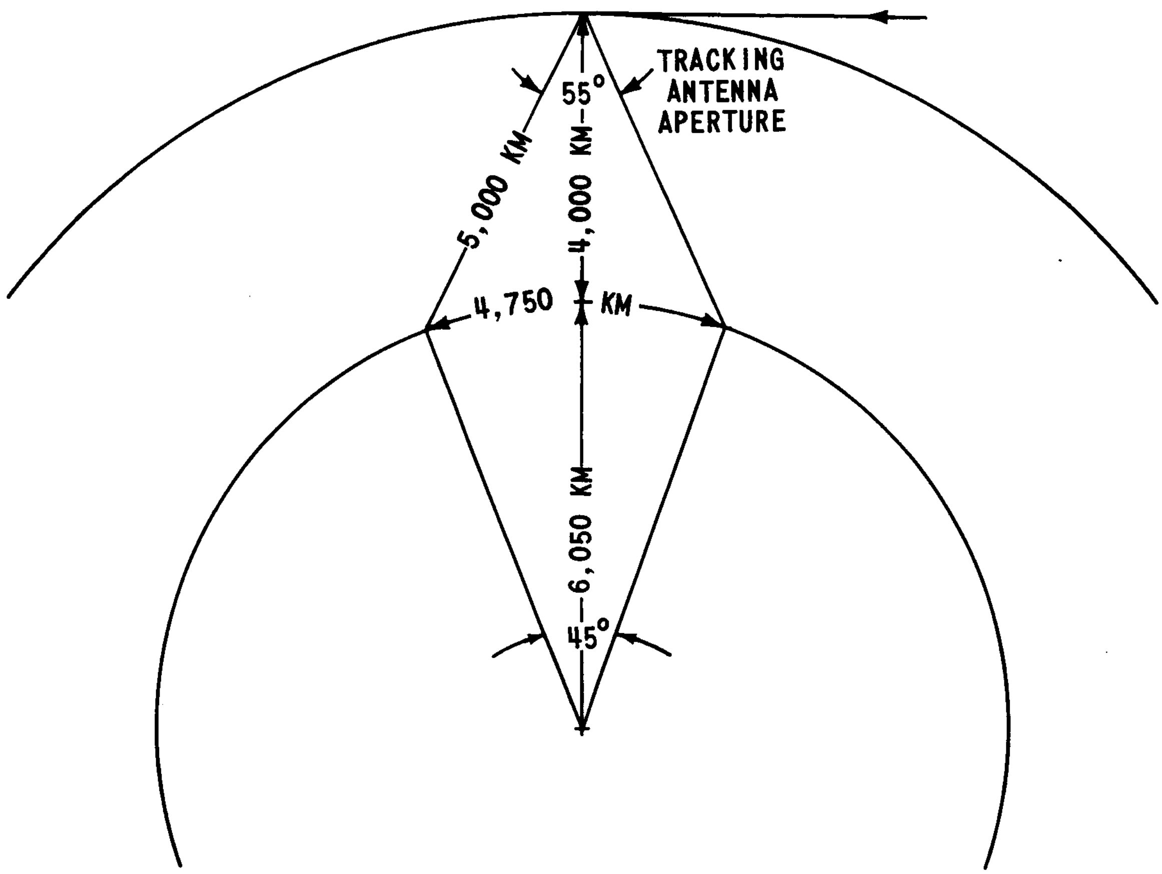


FIGURE 3 - BALLOON TRACKING AND DATA RELAY ORBITER TRACKING GEOMETRY

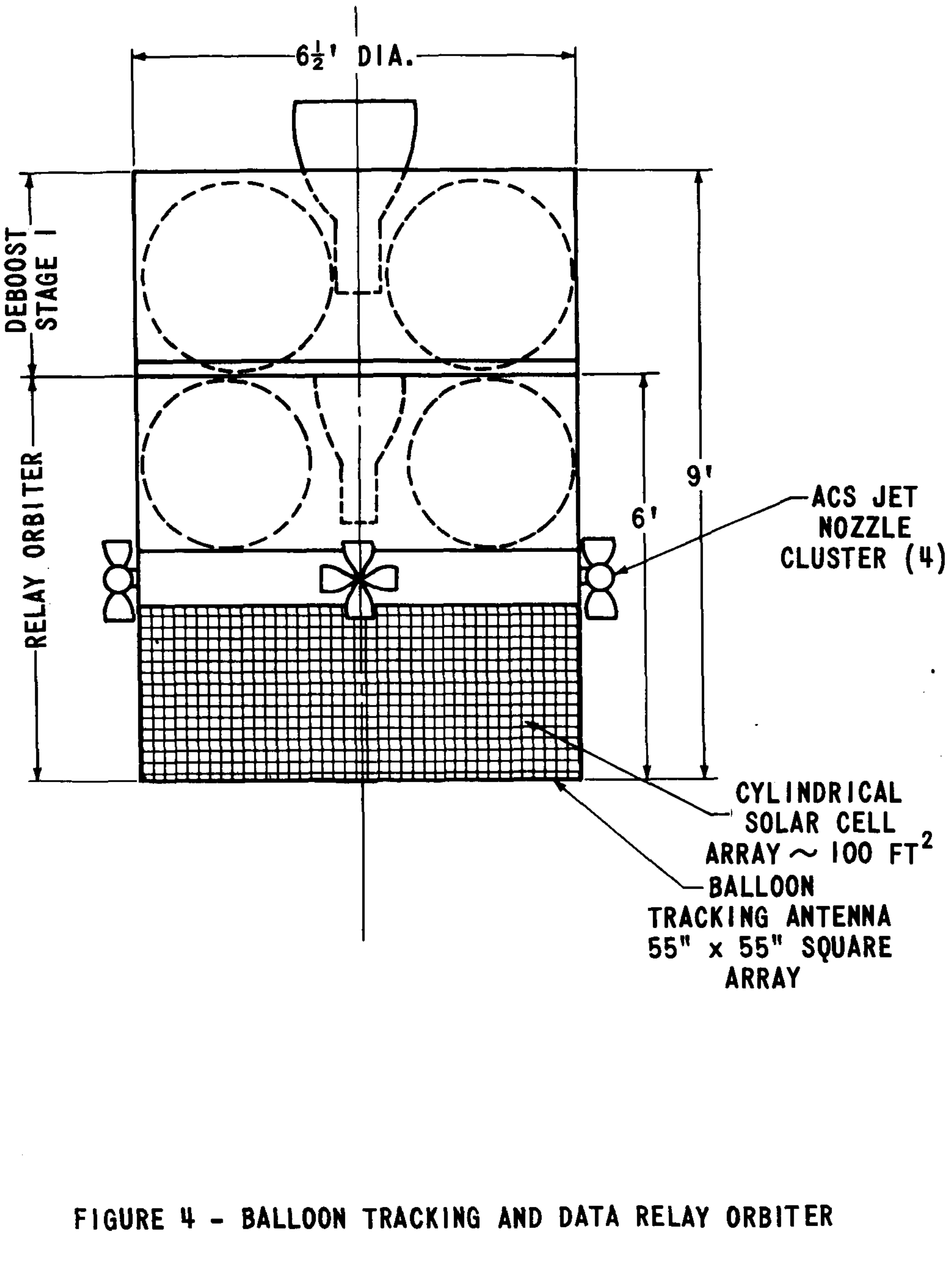


FIGURE 4 - BALLOON TRACKING AND DATA RELAY ORBITER

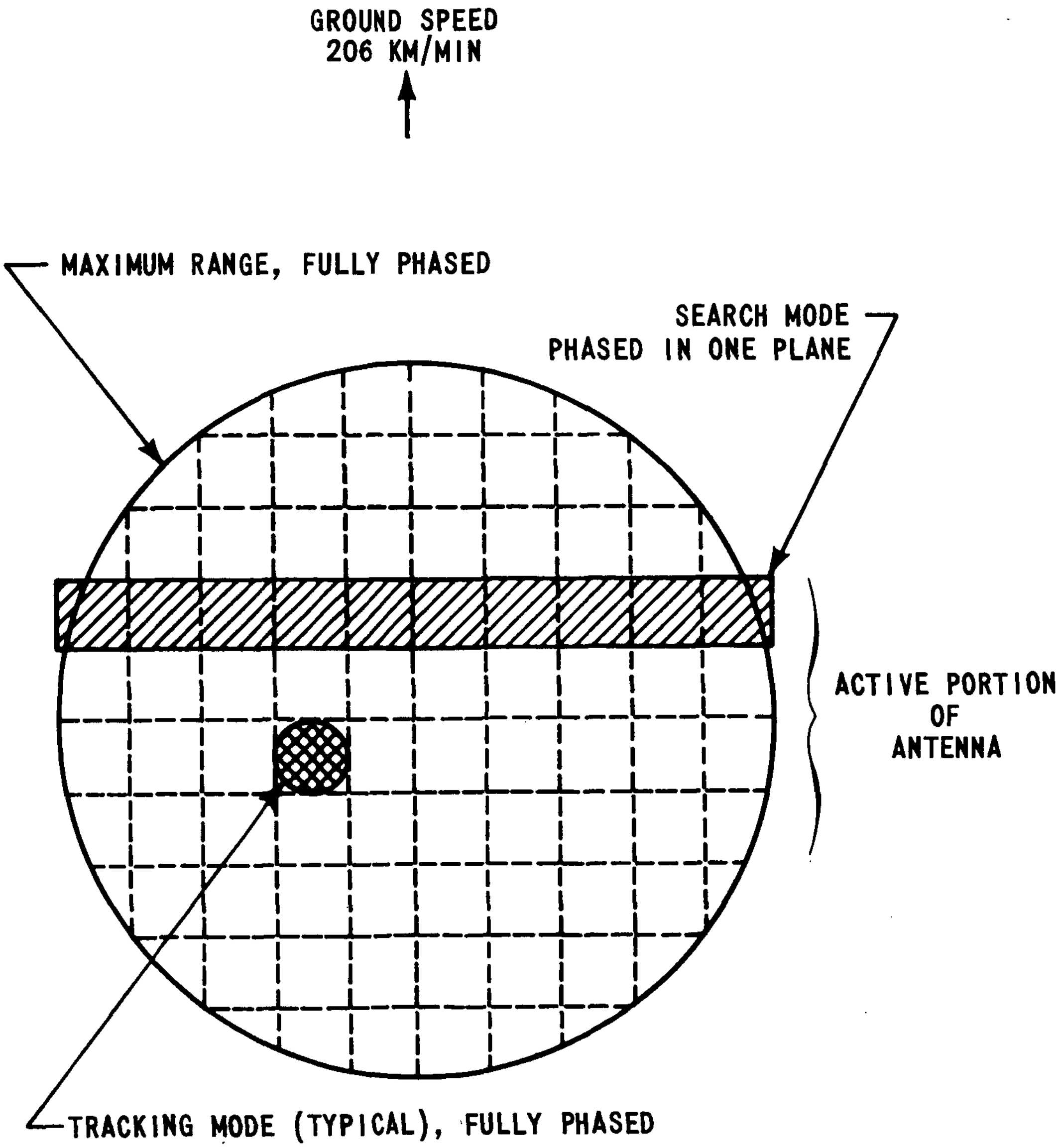


FIGURE 5 - TRACKING ANTENNA GROUND PATTERN

APPENDIX A

Tracking Subsystem

The tracking subsystem antenna ground pattern is illustrated in Figure 5. The pattern is generated by a square array, approximately 55 inches on a side, which is made up of 10 rows of 10 elements each. In the search mode the antenna is partially phased (one plane) and generates a "brush-type" beam 55° wide and 5° deep. The motion of the orbiter causes the beam to sweep the Venus surface.

When the search beam acquires a balloon, the antenna array focuses (fully phased array) on this balloon with a 5° conical beam and tracks the balloon as it moves across the antenna's pattern. In the fully phased array mode the beam is limited to the 55° angle of the antenna. This means that, if the 55° search beam were at the leading edge of the antenna ground pattern and a balloon were detected at the far left (or right) limit of the search beam, the antenna could not focus on it because the balloon would be outside the antenna beam (defined by the circle in Figure 5). For this reason the search beam is located at the fourth "row" and only the field defined by rows 4-7, inclusive, is actually used.

The operation of the system within the time line constraints is described by means of an illustrative example. Consider the case of the search beam acquiring all six balloons simultaneously. The orbiter will energize all six balloons and then focus on a balloon selected in accordance with a hierarchical logic. If the onboard computer does not reject the balloon response (see below), the balloon identification, location left or right of ground track, range, doppler, and meteorological data are entered into the onboard memory. This takes approximately 20 seconds, during which the antenna is electronically tracking the balloon. No antenna articulation or change in orbiter attitude is required.

When data acquisition is complete, the system will return to the search beam mode at the antenna location where contact with the previous balloon was completed. Since the balloon velocities relative to the surface are not expected to be more than 3 km/min, whereas the orbiter's ground speed is 206 km/minute, the motion of the balloons relative to the orbiter is negligible during the time of the orbiter passage.

APPENDIX A (cont.)

When the search beam is formed again, the balloons will still lie on a line approximately perpendicular to the ground track. Again the orbiter will energize all balloons in the search beam, since the beacons on the remaining five balloons will have shut down due to a timing switch[2] while the first balloon was being interrogated. The orbiter will then focus on a balloon selected in accordance with the hierarchical logic. However, if this balloon has already been interrogated, further contact will be terminated and the tracking system will focus on the next un-interrogated balloon.

When data acquisition is complete, the cycle is repeated until all six balloons are interrogated. Total elapsed time will be on the order of two minutes.

Should the balloons spread out <u>along</u> the ground track instead of across the ground track, there is no problem. The search beam will re-form at the location of the last completed acquisition and remain at the location until the next contact. At the orbiter ground speed of 206 km/minute there are more than 400 seconds of time available in the depth of the active portion of the antenna pattern. For six balloons this permits more than a minute contact with each balloon. Only 20-23 seconds are required.

Since the balloons will be deployed at diametrically opposite locations (Figure 2), the natural grouping of two sets of six each will be maintained during the expected life of the balloons. Therefore, it appears possible to turn off the tracking system (or reset it to zero) after the computer recognizes the acquisition of the sixth balloon. This could also be accomplished by a clock on the orbiter that is synchronized to the initial locations of the balloons and turns the tracking system on 45° before zenith passage and turns the system off 45° after zenith passage. This would allow for the situation where one or more of the six balloons no longer appears (either because it has been destroyed or has drifted too far).

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